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Development of a Transpondersonde for the Super-LOKI Meteorological Rocket

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13. ABSTRACT

This report discusses the results of an in-house AFCRL effort to design and develop a meteorological transponder rocketsonde. The rocketsonde was designed to be flown in the Super-LOKI rocket vehicle to an apogee altitude of about 75 km where it is ejected and descends on a "STARUTE", or stable parachute, while transmitting meteorological data. It is tracked by an automatic ground tracking station, Rawin Set AN/GMD-4, which demodulates the signals transmitted by the sonde to provide direct measurement of atmospheric temperatures, elevation and azimuth angles, and slant range. The angles and slant range are then used to compute wind velocity and the altitudes to which temperature and winds are assigned. It is this independent slant range measuring capability which distinguishes the transpondersonde from other types of rocketsondes, in that high precision radars are not necessary to obtain the wind and altitude data as is necessary with the nontransponder systems. As a result, meteorological rocket soundings can now be conducted in areas of the world where tracking radars are not available or cannot be suitably scheduled.

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Abstract

This report discusses the results of an in-house AFCRL effort to design and develop a meteorological transponder rocketsonde. The rocketsonde was designed to be flown in the Super-LOKI rocket vehicle to an apogee altitude of about 75 km where it is ejected and descends on a "STARUTE", or stable parachute, while transmitting meteorological data. It is tracked by an automatic ground tracking station, Rawin Set AN/GMD-4, which demodulates the signals transmitted by the sonde to provide direct measurement of atmospheric temperatures, elevation and azimuth angles, and slant range. The angles and slant range are then used to compute wind velocity and the altitudes to which temperature and winds are assigned. It is this independent slant range measuring capability which distinguishes the transpondersonde from other types of rocketsondes in that high precision radars are not necessary to obtain the wind and altitude data as is necessary with the nontransponder rocketsonde systems. As a result, meteorological rocket soundings can now be conducted in areas of the world where tracking radars are not available or cannot be suitably scheduled.

As a fallout from the transponder program, a new nontranspondersonde, or transmittersonde, was also developed. This instrument is basically the same design as the transpondersonde with the exclusion of an amplifier, receiver and antenna. The design, development and flight tests of both were performed during the period from approximately May 1969 through September 1971.

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1. GENERAL DESCRIPTION AND APPLICATION

Meteorological sounding rockets are used to obtain thermodynamic and wind data in the altitude regions above balloon-borne radiosonde heights. A typical balloon flight obtains these data from the earth's surface up to about 30 km altitude, while meteorological rockets go from about 65 km (apogee) down to 30 km. The majority of the sounding rocket payloads, known as transmittersondes, require high precision radar support to obtain positional and wind data of the descending instrument. Since some of the launching stations do not have such radars available, the development of a transponder rocketsonde was initiated at AFCRL in order to satisfy an Air Weather Service requirement to conduct meteorological rocket soundings in all geographical areas without regard to the availability of tracking radars.

The three meteorological rocket systems, in order of their development, which have been and are currently used for routine soundings employ the ARCAS, LOKI-Dart and the current Super LOKI-Dart vehicles. A transpondersonde payload, known as the AN/DMQ-9, has been successfully developed and flown operationally with the Arcas system. However, in recent years the cost of the Arcas system has increased considerably, which was the motivating reason for the development of the much lower cost LOKI-Dart system. A transmittersonde, or nontransponder payload, is

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currently used with this LOKI-Dart system. Two successive contractual efforts aimed at developing a transpondersonde for this system failed. The main reason for these failures is the small payload size limitation in the LOKI-Dart, necessitating the use of a solid state transmitter which yielded poor results.

As a result of these failures, the Super-LOKI-Dart system was proposed. The Super-LOKI system has a larger payload volume than that of the LOKI-Dart and permits the use of the proven vacuum tube in place of a solid state transmitter. This made the transpondersonde design feasible for this size of payload and culminated in the AFCRL development program.

The major assemblies of the transpondersonde are a 1680 MHz transmitter and antenna, an 82 KHz amplifier, a 403 MHz receiver and antenna, a meteorological data oscillator, a clock commutator, a DC/DC converter, a relay and "umbilical" connector, a 6.25 volt battery, and a temperature sensor and mount. Figure 1 is a block diagram depicting these assemblies. Physically the sonde measures 13 in. long, 1-5/8 in. in diameter, and weighs about 1 pound. Once assembled, the electronics are inserted into a cylindrical tube and encapsulated to provide both mechanical support and heat protection. The transmitter is located at one end of the tube with the 1/4 wavelength dipole antenna (about 2 in. long) protruding (see Figure 2). The temperature sensor is mounted at the other end behind the battery pack (not shown in Figure 2).

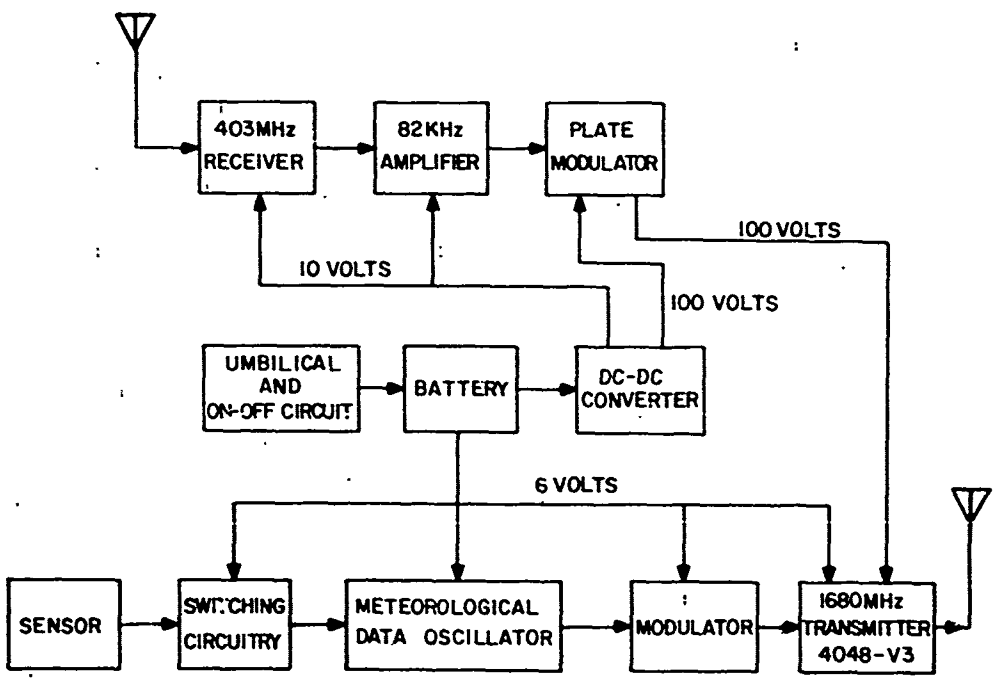


Figure 1. Block Diagram—Super-LOKI Transpondersonde

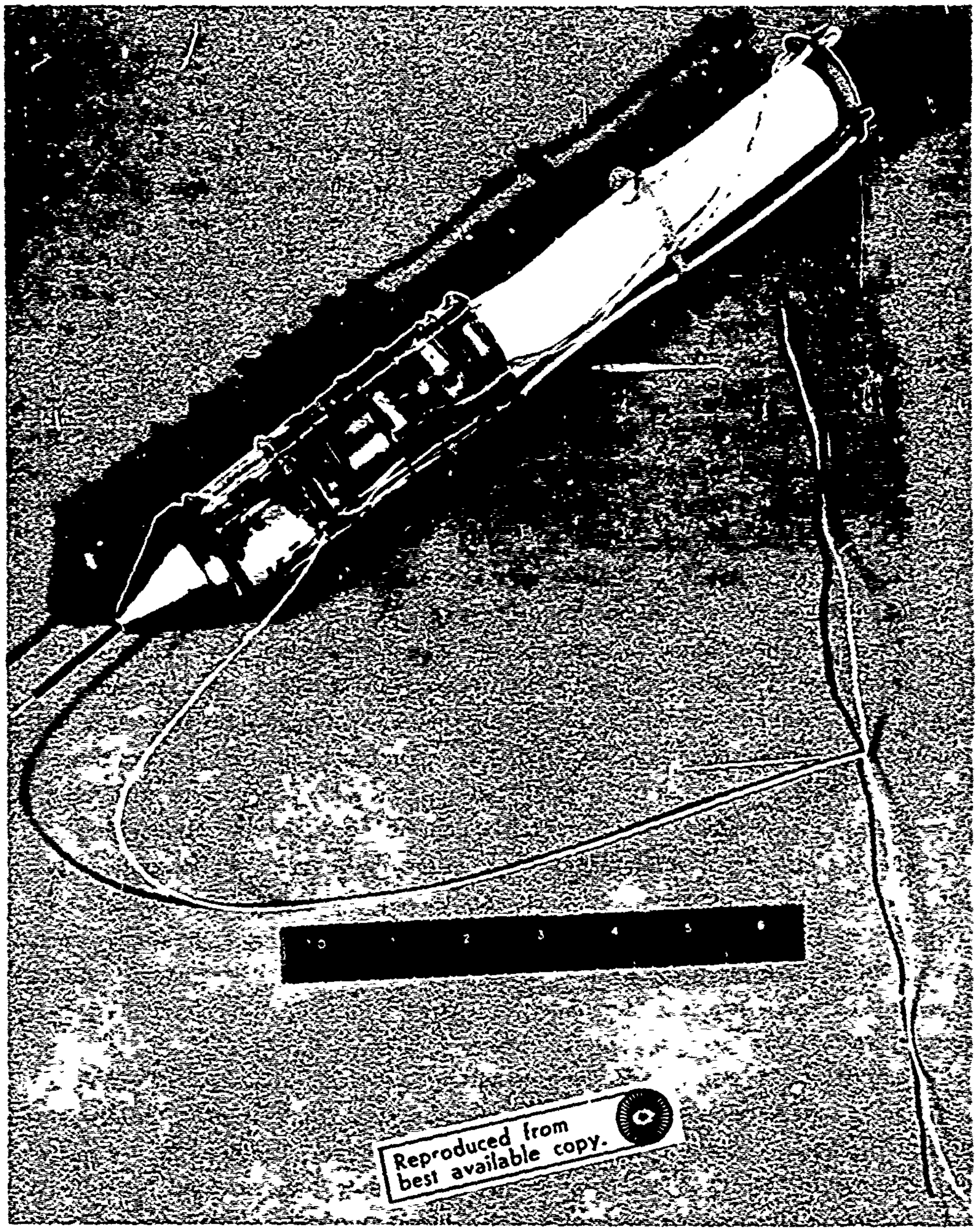


Figure 2. Super-LOKI Transpondersonde

2. INITIAL DESIGN CONSIDERATIONS

The primary considerations in the design of the transpondersonde were compatibility with both the Rawin Set AN/GMD-4 and the Super-LOKI-Dart vehicle. The designs of past and current transpondersondes were examined with these requirements in mind. For example, the AN/DMQ-9 was the only operationally successful transponder rocketsonde up to this time, so its receiver and amplifier were redesigned and repackaged to suit our application. The 1680 MHz transmitter tube was preferred to a solid state version because of cost and frequency stability problems and the two prior contractual failures attributable primarily to the solid state transmitter. As a result, it became necessary to incorporate a DC-to-DC converter in the sonde to supply the plate voltage (115 VDC) to the tube and 11 VDC to the receiver. A solid state commutator from one of the previous contractual attempts appeared promising and later proved to be very satisfactory in this sonde. A nickel cadmium battery was chosen to provide adequate capacity and shelf life along with a recharging capability.

Both transmitting and receiving antennae had to be extremely limited in size and shape due to the payload volume of the vehicle. As a result, there was very little leeway in the choice of a transmitting antenna, except that a minimum VSWR and an "acceptable" antenna pattern had to be achieved. Thus, the standard radiosonde cone and dipole arrangement was chosen, which is not optimum, but which has proven satisfactory. Adequate signal strength has been obtained with this antenna, but the same problem of high elevation angle signal dropout is still present. A relatively major redesign effort would be necessary to solve this problem.

The 403 MHz receiving antenna was also limited in configuration primarily by space limitations although two designs were tested: a wrap-around type and a coaxial center fed 1/4 wavelength dipole. The coaxial antenna was chosen because it presented less RF interference with the transmitting tube. It is physically attached to a lanyard which attaches the sonde to the parachute (STARUTE) and has performed well during the flight tests.

Several potting compounds were investigated and one was selected which had a satisfactory dielectric constant and was relatively easy to handle. A mold was constructed to house the sonde during the potting procedure. The need for a remote on/off capability resulted in a relay inside the sonde with an external "umbilical" cable which is also used to charge the batteries and to run the instrument on external power.

A protective cup, similar to the one used in the standard LOKI-Dart system, was designed to protect the thermistor and mount. This cup falls off after ejection

(at apogee), allowing the thermistor bead to measure atmospheric temperatures during the descent.

Throughout the initial design phases, a constant effort was maintained to "value engineer" the sonde to select the most reliable and reasonably priced components. Also, attempts were constantly made to keep the sonde cost down by designing it to lend itself directly to production methods.

3. DESCRIPTION OF MAJOR COMPONENTS

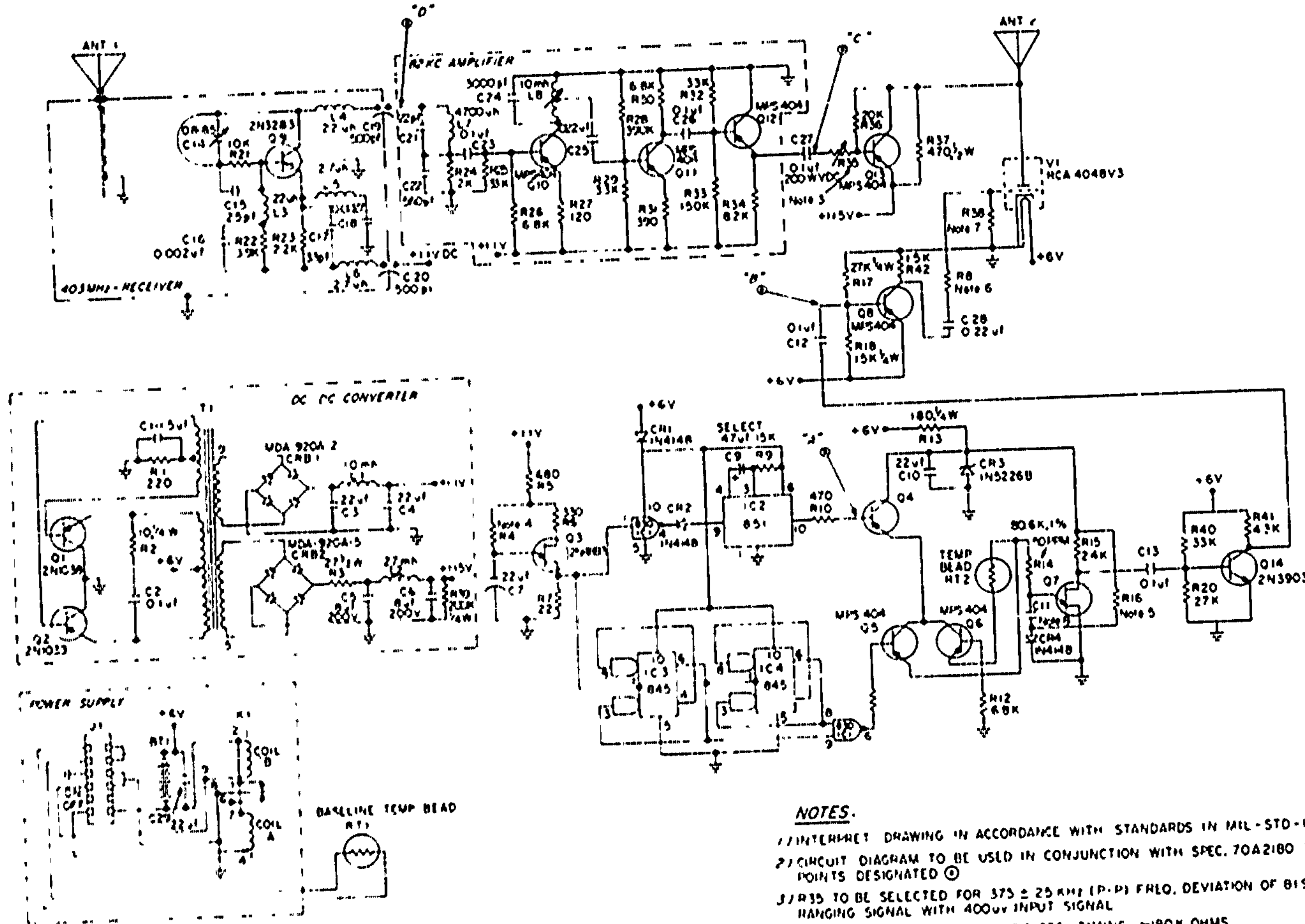
3.1 Transmitter and Antenna

The transmitter consists of a fundamental 1680 ±20 MHz tunable RF cavity oscillator. The RCA 4048V3 tube was used for most of the flight tests. It supplies approximately 400 milliwatts output and can be either FM or AM modulated. The meteorological pulses FM modulate the grid with 200 ±50 KHz negative peak-to-peak deviation. The 81.94 KHz ranging signal FM modulates the plate with 375 ±25 KHz peak-to-peak deviation (see Figure 3). Recently a new RCA tube, Number 4084 (originally A15618), has been tested with promising results in that frequency shifts have been lowered.

The transmitting antenna consists of a quarter-wave dipole stub and a conical ground plane. The antenna radiation pattern has a deep null along the cone axis, which is typical of dipole patterns. It radiates a linearly polarized wave. The combination of antenna pattern and polarization causes excessive signal dropouts at high elevation angles (70°), but has a relatively steady signal strength pattern below 70°. However, this creates a problem at stations where the sonde repeatedly descends overhead at these higher elevation angles. In the final analysis, however, both the tube and the transmitting antenna presented few problems in the flight tests.

3.2 Receiver and Amplifier

The receiver is a nominal 403 MHz single stage, self-oscillating, super regenerative type. It requires RF shielding to maintain oscillation due to the external capacitive and inductive effects at UHF frequencies. This type of receiver is characterized by its continuous oscillation frequency called the "quench" signal. This is a sawtooth type buildup and decay signal of about 1.5 Vpp and a 2.5 μsec period (400 KHz) which the 2N3283 (Q-9) stage generates. The period and amplitude of the sawtooth is determined principally by C-18 in the emitter circuit of Q-9 (see Figure 3). The quench frequency is lower than the carrier frequency (403 MHz) and higher than the ranging modulation frequency (82 KHz) to prevent interference between the signals.



NOTES.

1/ INTERPRET DRAWING IN ACCORDANCE WITH STANDARDS IN MIL-STD-100

2/ CIRCUIT DIAGRAM TO BE USED IN CONJUNCTION WITH SPEC. 70A2180 TEST POINTS DESIGNATED ⊙

3/ R35 TO BE SELECTED FOR 375 ± 25 KHz (P-P) FREQ. DEVIATION OF 81.94 KHz RANGING SIGNAL WITH 400uv INPUT SIGNAL

4/ R4 TO BE SELECTED FOR 5 ± 0.5 SEC TIMING, ~180K OHMS

5/ R16 MAY VARY FOR EACH TRANSISTOR (Q7) LOT, 1.5 TO 3K APPROX

6/ R8 TO BE SELECTED FOR 350KHz NOMINAL DEVIATION

7/ R38 TO BE SELECTED FOR 30ma PLATE CURRENT ON V1

8/ C11 TO BE SELECTED FOR REFERENCE FREQ 190 ± 15 KHz

Figure 3. Circuit Diagram Transponder

As the detector goes in and out of self oscillation, the 403 MHz carrier signal, 82 KHz ranging signal, and 400 KHz quench signal comprise the components on the collector circuit of Q-9. The 403 MHz and 400 KHz signals are attenuated by two tuned stages of L - C filtering which allow only an 82 KHz signal to reach the 82 KHz amplifier. This 82 KHz amplifier consists of four MPS404 transistor stages. The first two stages (Q-10 and Q-11) provide the majority of the gain while the last two stages (Q-12 and Q-13) provide impedance matching to the transmitting tube.

3.3 Receiving Antenna and Lanyard

As previously mentioned, the receiving antenna consists of a center fed 1/4 wavelength dipole made up of a 50 ohm miniature coaxial cable. The total length is approximately 23 in., with 6-1/2 in. (1/4 wavelength) stripped back on one end. This end is physically attached to the lanyard. The other end is stripped back about 1/2 in. and fed through the top of the receiver "can". Here the two 1/2 in. leads are soldered to the bottom of the can and inductively coupled to the base of transistor Q-9. This results in a DC short circuit, but it provides satisfactory energy transfer at 403 MHz to transistor Q-9, while limiting the bandwidth to prevent radio frequency interference from other frequencies near 403 KHz.

A copper wrap-around antenna was built and tested since it is a much easier antenna to handle as it does not depend on the lanyard configuration for its deployment. However, after several flight tests, it was found that it caused loss of 1680 MHz carrier when the sonde was enclosed inside the dart. Since it is necessary to preset the transponders and baseline both sondes, this proved to be an unsatisfactory situation. On several of the flights, a good 82 KHz ranging signal was received using this antenna, although it was not superior to the signal received from the coaxial antenna. Several lengths of the coaxial antenna were tested, but 23 in. was found the most convenient length to tie it to the lanyard. This is not a critical electrical length.

3.4 Clock–Commutator and Meteorological Data Oscillator

The meteorological data oscillator (MDO) is commutated by a two-channel solid state commutator that provides temperature and reference data channels. The sequence provided by the commutator is of three temperature and one reference data periods. Each data period has an on-time of 4.5 seconds and an off-time, or blanking period, of 0.5 seconds.

The clock commutator consists of a 0.2 Hz (one pulse every five seconds) clock, two 845 micrologic flip-flops (IC3 and IC4), one 830 dual two-point micrologic NAND gate (IC1), one 851 micrologic monostable multivibrator (IC2), and three switching transistors–Q4, Q5, and Q6 (see circuit diagram, Figure 3).

3.4.1 CLOCK

The clock, transistor Q3, is a basic unijunction relaxation oscillator. This provides two outputs: one is used to trigger channel selector flip-flops IC3 and IC4, and the other output is applied to one-half of the NAND gate IC1 where it is shaped and inverted to trigger the monostable multivibrator IC2.

A channel selector consisting of flip-flops IC3 and IC4 divides the incoming clock pulses f by 2, thus providing f/2 and f/4 outputs. By combining f/2 (IC-3 pin 6) and f/4 (IC4 pin 6) with one-half of the NAND gate IC1, a pulse width of five sec. duration is available for every four clock pulses (see timing diagram, Figure 4). The output of IC1 pin 6 is used to turn on transistor switch Q5. This, in turn, places +3.3 VDC at the junction of the temperature sensor and R-15 (reference resistor), thus effectively switching out the temperature sensor. This action allows a reference signal frame to be generated by the MDO for the duration of the five sec. pulse. Transistor Q6 is normally ON, and with the exception of the reference frame period and blanking period, it permits the MDO to generate the temperature signal pulses.

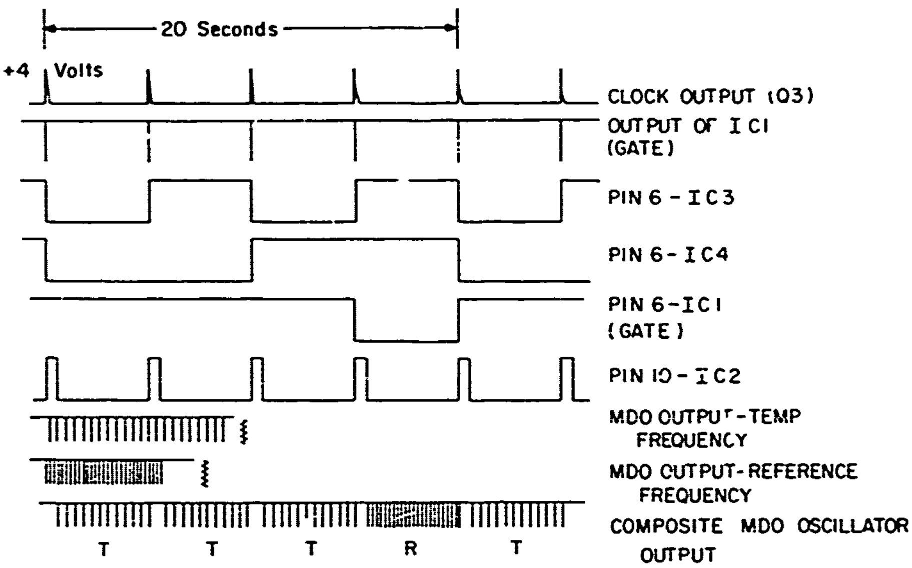


Figure 4. Timing Diagram

Monostable multivibrator (IC2) generates a 0.5 sec. pulse for each clock pulse input. The pulse width is determined by the external elements C9 and R9. The output of the IC2 (pin 10) is coupled to transistor switch Q4 through R10.

A 0.5 sec. positive output pulse from IC2 turns off Q4. This action removes the +3.3 VDC to Q5 and Q6 which, in turn, inhibits the MDO for the 0.5 sec. pulse duration. The composite results, shown in Figure 4, provide three temperature periods and one reference period with an ON time of 4.5 sec. for every four clock input pulses.

3.4.2 METEOROLOGICAL DATA OSCILLATOR (MDO)

The MDO is basically an asymmetrical unijunction multivibrator circuit. The length of time that Q7 is OFF is primarily determined by R14 and the temperature sensor resistance. The length of the ON-time is determined primarily by R16. For complete analyses of this circuitry, refer to GE Transistor Manual, 7th Edition, pages 339-340. The output frequency of the MDO is primarily determined by C-11 and the resistance of the reference resistor (R-14) and/or the temperature sensor resistance. The frequency of the MDO is inversely proportional to the input resistances. With the temperature sensor shorted out and R14 fixed at 80.6 KΩ, C-11 is selected to generate a reference frequency of 190 ±15 Hz. R-16 is selected to provide a 100 ±25 microsecond meteorological data pulse width. The output of the MDO is coupled to transistor Q-14 where it is inverted and amplified. The output of Q-14 is coupled to Q-8, where it is again inverted to provide a negative going pulse to grid modulate the transmitter tube. The reference frequency and meteorological pulse width and amplitude were selected to be compatible with the Rawin Set AN/GMD-4.

3.5 DC-to-DC Converter

As mentioned previously, once the decision was reached to use the tube transmitter, it became necessary to incorporate a DC-to-DC converter. This was due to the size and weight limitations of the transpondersonde; that is, a large battery pack could not be tolerated.

With a 6-volt battery input, the converter supplies 115 VDC at 30 ma and 11 VDC at 15 ma. These supply the tube plate/82 KHz amplifier voltages and the receiver/82 KHz amplifier voltages respectively. The voltage supply for the MDO and transistor switches is provided from a 3.3 VDC Zener diode and dropping resistor from the 6-volt battery.

The nominal frequency of oscillation of the converter is 2.2 KHz and was so selected to minimize core losses and not interfere with the 82 KHz amplifier or the meteorological data (15-200 Hz). The primary and secondary winding outputs are square waves generated from the asymmetrical conduction of Q-1 and Q-2, which alternately create a magnetic field hysteresis buildup and breakdown in the windings. The two square wave outputs are connected to two diode bridges (CRB1

and CRB2) which result in a DC voltage output which contains spikes due to the transistor switching times. These spikes are eliminated by π filters at the diode bridge outputs. An attempt to diminish the noise spikes using ferrite beads gave mixed results in that they could not be duplicated. As a result, the L - C filters are presently used for this purpose.

3.6 Battery

Since a normal rocketsonde flight lasts about 40- 45 minutes, not including ground tests, we felt that a battery which could operate the sonde for one hour would be sufficient. The total instrument current drain is close to 1 amp, so a 1 ampere-hour battery was necessary along with a recharging capability. A group of five 1.25 VDC nickel cadmium cells connected in series to make a 1-3/4 in. diameter, 5 in. long, 8-ounce battery pack was finally selected. When fully charged, the voltage output runs close to 7 volts and has a plateau above 6 volts for one hour at 1 amp current drain. As with all of the other components, the battery was limited in size by the sonde dimensions, so more than one hour of running time would require a larger battery pack.

3.7 Mount and Sensor

Two mount configurations were tested: a two-post and a four-post mount. The two-post mount was adopted at the end of the program because much more test data had been accumulated on it up to that time. However, the four-post mount should be tested further since it is less sensitive to shock and vibration and provides for redundant sensor leads. This should prove to be a more reliable configuration and further testing is warranted.

The sensor consists of an aluminized 10 mil, 5 K-ohm (nominal) bead which is compatible with the sonde meteorological blocking oscillator. Three aluminized 5 mil, 3 K (nominal) beads were also flight tested. These beads provide a basis from which the meteorological data oscillator could be redesigned to obtain an extended temperature range. Only minor redesign would be necessary, but there are trade-offs involved in terms of accuracy at either the cold or warm temperature. A 33 pf chip capacitor is attached in parallel with the bead thermistor to provide shunting which minimizes RF heating of the bead. The leads to which the bead is soldered are about 1 in. long.

A separate temperature sensitive bead is placed at the bottom of the sensor mount with two leads out to the umbilical connector. A meter, which displays the temperature this bead senses (in °C), is attached to the umbilical connector. This temperature is compared to the temperature sensed by the thermistor and they should agree within 3°C. In this manner, a baseline (or calibration check) capability

is provided which gives assurance that the thermistor and electronics are operating properly prior to a launch.

3.8 Remote Control Capability

It soon became evident that a requirement to turn the sonde ON and OFF and power it externally (for example, not from its own battery) was a highly desirable feature. The battery is only rated for one hour (maximum) under load, and in some cases, such as ground tests or long holds at a test range, this may not be enough time. Thus, a "remote control box" is utilized which has the following features:

(a) It can turn the sonde ON and OFF through a cable attached to an "umbilical" connector (J1) in the sonde

(b) It can power the sonde externally

(c) It can recharge the sonde batteries.

When it is desired to power the sonde on its own batteries, relay K1 is activated by the remote control box and completes the ground to the 6 VDC battery.

The remote ON-OFF capability proved itself to be extremely valuable at the test ranges as in several instances long holds (more than 10-15 minutes) were encountered in the final countdown before launch. An operator did not have to leave the blockhouse, go to the launcher, lower the dart, and turn the sonde OFF. All he had to do was to flip a switch at the blockhouse. Surprisingly, the umbilical connector attached to the dart survived the launches in good condition and was reusable. A summary of the listing of the electrical specifications is presented in Table 1.

Table 1. Electrical Specifications—Transpondersonde

Transmitter	
Type	Tube RCA 4048V3
Power Output	100 Milliwatts (minimum)
Frequency	1670-1695 MHz (tunable)
Sensor Modulation	FM
81.94 KHz Range Signal Modulation	FM
403 MHz Receiver	
Tuning Range	400-406 MHz
Sensitivity	50 μv Minimum
50 db Bandwidth	392-415 MHz
81.94 KHz Amplifier	
Tuning Range	75-82 KHz
Modulation	375 KHz Peak to Peak (FM)
Type of Modulation	Plate

Table 1. Electrical Specifications—Transpondersonde (Cont)

Commutator	
Sequence	T T T R, ...
Duration	5 seconds each
Channel Break	0.5 second
Meteorological Data Oscillator	
Reference Frequency	190 Hz
Pulse Amplitude	200 KHz Peak to Peak (FM)
Pulse Width	100 μsec
Calibration	22 points
Type of Modulation	Grid
DC/DC Converter	
Input Voltage	6.25 VDC
Output Voltages	11 and 115 VDC
Current Drain	
Instrument	1 amp maximum
Tube Plate	30 milliamps
Size	13.25 in. long; 1.640 in. diameter
Weight	480 grams (nominal)

4. MECHANICAL CONFIGURATION

As previously mentioned, the size of the sonde was limited by the Super-LOKI-Dart vehicle dimensions. The dart had space for about a 13 in. long × 1-3/4 in. cylindrical payload, so these constraints were firm from the outset of the program. Our goal was a sonde weighing no more than one pound so that a reasonable descent rate through the atmosphere could be maintained when used with the Super-LOKI STARUTE. This goal was attained, as the final sonde weights are very close to one pound, with the only significant variable being the density of the potting compound.

With these constraints in mind, components—printed circuit board, DC-to-DC converter, receiver, etc.—were designed in order not to exceed these overall dimensions. The outer diameter of the sonde, plus potting material, is 1.645 in. After the sonde is potted, it is inserted into a fiberglass tube (10-7/8 in. long × 1.656 in. diameter) and epoxied in place. The purpose of this tube is to enhance the structural integrity of the sonde.

There are numerous reasons why the subassemblies were configured as they were in the sonde. For example, the 1680 MHz transmitting tube is as far away from the thermistor bead as possible to avoid R.F. heating of the bead. At the same time, the transmitting dipole must make electrical contact with the dart ogive

in order to ascertain the sonde is operative prior to a launch. The lanyard is located above the sonde center of gravity such that the inclination angle of the sonde exposes the bead for optimum atmospheric temperature sensing. This avoids contamination of the air flow around the bead. Heavier gauge ground leads are strung from the battery along the length of the sonde to provide good electrical grounds and add to the structural strength. It was found that soldering two of these ground leads to the 403 MHz receiver shielding reduced the DC-to-DC converter noise spikes present in the modulating signals (Section 3.3).

Four different materials were tested for the lanyard: nylon, fiberglass, wire, and teflon. Of the four, only teflon proved satisfactory. The nylon lanyard literally melted under the high temperatures of a flight ascent. The fiberglass lanyard was marginally acceptable in that it was flown successfully, but we observed that it broke if bent in a sharp angle. However, the use of fiberglass was curtailed, since it was felt this may occur to a certain number out of a large production lot. A wire lanyard was flown to get some flights where the sonde was known to have stayed attached to the STARUTE, but it interfered with the RF signals because it is a conductor close to the transmitting tube. Therefore, teflon was recommended for use as the lanyard. Originally this teflon was acquired by stripping it off of #12 gauge wire, but commercial spools of teflon tubing were finally located and used.

A foam-in-place liquid potting compound (ECCOFOAM FPH) was used to encapsulate the sondes after assembly. The compound was selected because of its high temperature resistance (400°F), low dielectric constant (1.05) at microwave frequencies, and ease of handling. A special reusable mold was made out of aluminum because of its high heat capacity. Once the potting compound is poured and heat cured, it becomes rigid, giving the sonde a pink coloring. This is then epoxied into place in the fiberglass tube mentioned earlier.

An electrical "umbilical" connector is located about half-way down the sonde length (Section 3.4). With the remote control box in use from the blockhouse, it is necessary to leave the umbilical cable connected to the sonde connector right up to the launch. Therefore, the connector is angled 45° down to provide a smooth cable pull-away at launch. This worked very well, and the same umbilical cable has been reused on several flights before it needed replacing.

5. ENVIRONMENTAL TEST RESULTS

The sonde was subjected to temperature and shock tests during December 1969, prior to the flight tests. No empirical data was listed following the temperature tests, although it was observed that the receiver stopped operating and the 82 KHz

phase shift became excessive below -30°C. One approach to try to solve this was to fill the receiver can with potting compound, but no improvement was noted. The subsequent flight tests indicated that low temperatures of this magnitude are not experienced during a flight. Also, the receiver and amplifier are located next to the transmitting tube so they benefit from any internal heat generated from the tube. Extreme heat caused thermal runaway of the transistors, but fortunately, these high temperatures are not encountered in a flight. The capacitors used originally to filter the converter spikes went outside acceptable tolerances at low temperatures so a more expensive electrolytic type was used which maintained a closer tolerance at low temperatures.

The shock tests were performed in a local testing laboratory. With the sonde loaded in the dart, which was in turn mounted on a test jig, the entire assembly was subjected to a half sine wave, peak 205 g, 5 millisecond shock test. One impact was performed along the longitudinal axis. After the test, the sonde was checked and found to be inoperative. Upon further investigation, it was discovered that the 1680 MHz transmitter antenna had separated from the tube connector. Upon replacement the sonde was again operative. Therefore, as a result of the shock testing, it was decided to epoxy the sonde inside the tube and also at the base to hold it in place. No further environmental tests were conducted at this time since time was running short, and it was felt that the flight tests would prove out the final design. However, there was a greater degree of confidence in the electrical design and structural integrity of the sonde as a result of these limited environmental tests.

Much later in the flight series, a dart which was painted white was tested. The problem was that the internal temperatures increase to unacceptable levels if the dart is in the sun for a period of time prior to a launch. After one hour, the internal temperature of the white dart was 12°C cooler than the standard black dart. Further investigation may be warranted in this area before any modifications are recommended.

6. FLIGHT TESTS AND DATA ANALYSIS

A summary listing of all the transponder Super-LOKI flight test results is presented in Table 2. High precision tracking C-band radars were used on every flight to verify performance. Rawin Set AN/GMD-4 was also used on every flight since it has a "coarse ranging" capability (Georgian, 1970). These tests were performed at the Air Force Eastern Test Range, Cape Kennedy Air Force Station, Florida.

As is shown in Table 2, the absolute mean error, algebraic mean error, and standard deviation have been computed for altitude, slant range, and elevation and

Table 2. Summary of Flight Data

Flight No.	No. Obs.	Absolute Mean Error				Algebraic Mean Error				Standard Deviation			
		Altitude (Ft)	Slant Range (Yds)	El. Angle (Deg)	Az Angle (Deg)	Altitude (Ft)	Slant Range (Yds)	El. Angle (Deg)	Az Angle (Deg)	Altitude (Ft)	Slant Range (Yds)	El. Angle (Deg)	Az Angle (Deg)
1	81	717	327	0.53	0.18	-182	-327	+0.65	-0.03	1060	413	0.25	0.31
2	79	462	244	0.70	0.44	+ 80	-207	+0.61	-0.26	712	150	0.53	0.51
3	77	856	157	0.70	0.55	+745	+ 47	+0.66	-0.37	1055	278	0.37	0.84
4	75	437	258	0.13	0.07	-400	-258	-0.01	-0.58	313	36	0.15	0.07
5	76	202	81	0.12	0.08	+179	- 58	+0.06	-0.05	174	114	0.10	0.14
6	72	538	284	0.28	0.14	- 31	-185	+0.13	0	886	290	0.36	0.24
7	73	341	34	0.19	0.13	+133	- 15	+0.03	-0.01	374	64	0.22	0.15
8	79	418	170	0.53	0.30	+122	-170	+0.52	+0.01	475	51	0.36	0.35
9	79	448	101	0.50	0.41	+212	-100	+0.43	-0.23	508	45	0.45	0.55
10	79	413	104	0.50	0.43	+224	-103	+0.44	-0.18	462	57	0.37	0.84
Average		483	176	0.43	0.27	+108	-138	+0.35	-0.17	602	150	0.32	0.40

azimuth angles. Also, Figures 5 through 14 show the altitude errors for each of the 10 flights. It is important to note that the altitude accuracies are dependent on both the slant range and elevation angle. For this reason, the 82 KHz range preset procedure becomes critical since it directly affects the final ranging resolution on any given flight. Also, proper alignment of the GMD pedestal is important since the elevation angle also enters into the altitude computations.

A typical flight slant range may go from about 80,000 yards near apogee down to 45,000 yards at test termination at 26,600 yards altitude (the GMD-4 measures slant range in yards). Thus, when an average range of 60,000 yards is used, the absolute mean error of 176 yards yields about a 0.29 percent ranging system accuracy as compared with radar. The fact that the algebraic and absolute mean errors are close in magnitude indicates that a ranging bias remains constant for any given flight once the 82 KHz preset is obtained. This is why the preset error should be minimized, since it determines the magnitude of the bias even though the minute-to-minute slant range change compares very favorably with radar.

Figures 5 through 14 show how the altitude errors varied for each flight when compared with radar. The generally negative values obtained on Flights 4 and 6 are due to a negative range bias probably due to the preset. At the higher elevation angles encountered on a rocketsonde flight, the altitude computations are more dependent on the absolute slant range accuracy than on the elevation angle. As shown in Table 2, the altitude algebraic mean error is +108 ft with a standard deviation of 602 ft. These errors can be improved upon by alignment of the GMD-4 pedestal and a more accurate slant range preset. Efforts to attenuate the 403 MHz power output while presetting appear promising, but more flight data are necessary.

7. CONCLUSIONS

In flight tests at the Air Force Eastern Test Range, the transpondersonde has performed very well. Refinements are still being made to increase the reliability and accuracy of the system, but the basic design has been proven satisfactory.

The problem of high angle signal dropout cannot be solved without a redesigned transmitting antenna. This is a difficult problem in the present payload size restrictions. Also, frequency shifts at ejection have been and are still a problem, although efforts at modifying the tube and/or the antenna have yielded encouraging results. The 1680 MHz solid state transmitters are still not used although they are not discounted as a possible eventual alternative to the tube.

The data will be reduced after each flight series to see whether or not different methods of presetting and baselining may increase the accuracy and ease of handling of the Super-LOKI transpondersonde system. One important aspect of this program

not previously mentioned is that it resulted not only in a transpondersonde, but also a non-transpondersonde, or transmittersonde. This transmittersonde contains the same circuitry as the transpondersonde, with the exclusion of the 82 KHz amplifier and 403 MHz receiver and antenna. It is flown in areas where high precision radars are available to track the reflective STARUTE to obtain positional data, while only the meteorological data are received and recorded at the GMD site. In a given time period more transmittersondes than transpondersondes are flown, the ratio being about 4:1, so although transmittersondes are a "by-product" of this program they constitute the major portion of the Meteorological Rocket Network soundings.

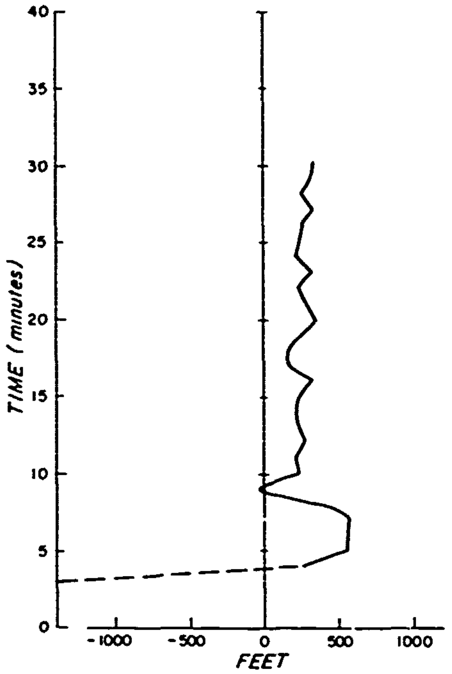


Figure 5. Altitude Differences, Flight 1

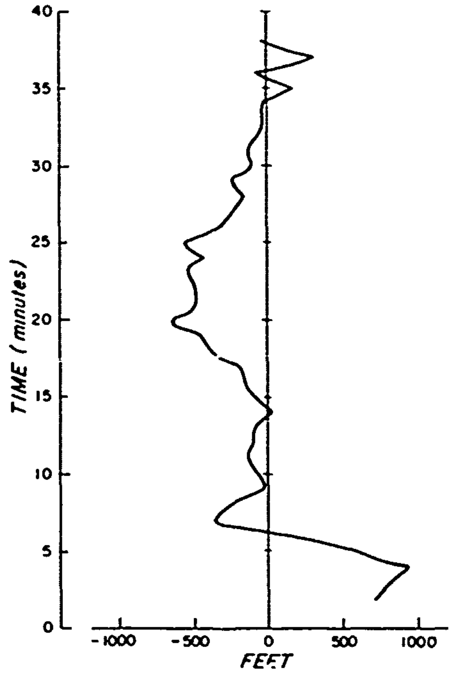


Figure 6. Altitude Differences, Flight 2

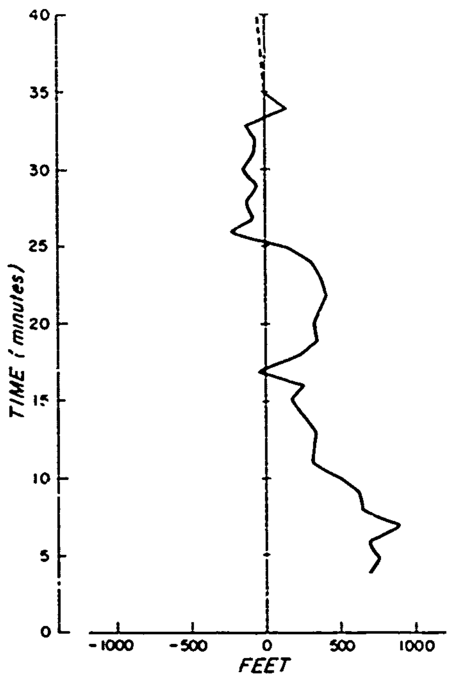


Figure 7. Altitude Differences, Flight 3

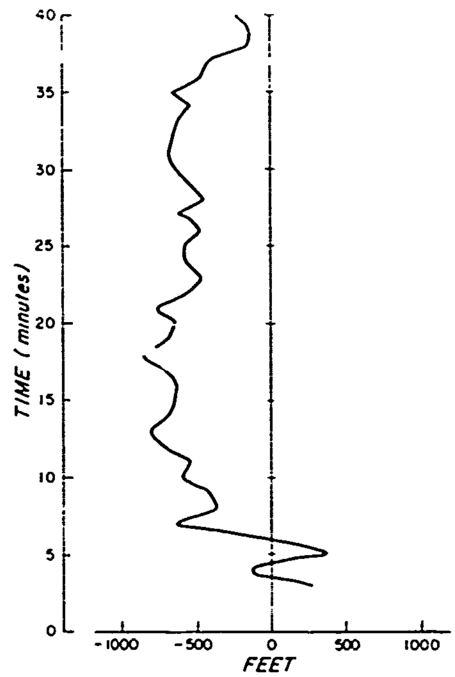


Figure 8. Altitude Differences, Flight 4

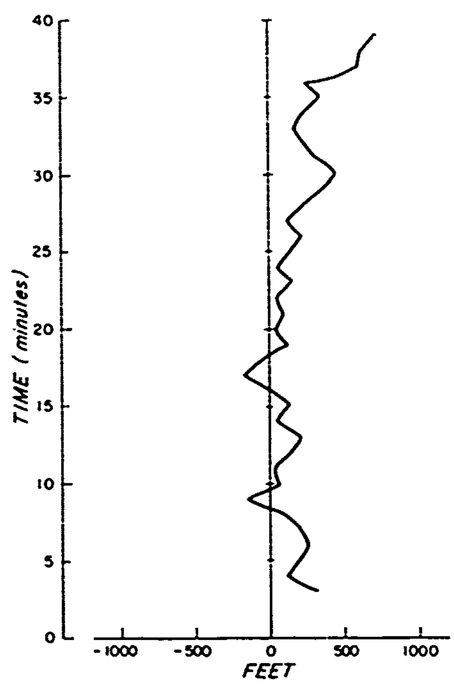


Figure 9. Altitude Differences, Flight 5

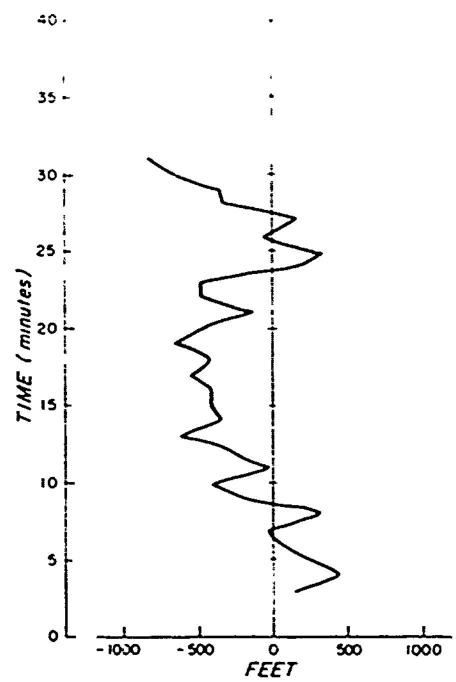


Figure 10. Altitude Differences, Flight 6

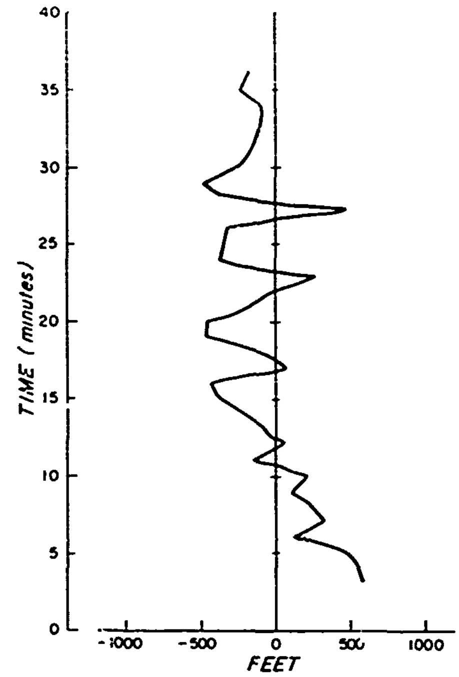


Figure 11. Altitude Differences, Flight 7

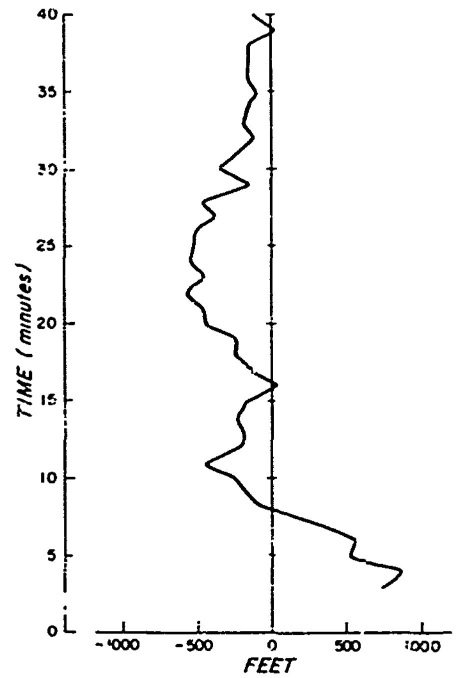


Figure 12. Altitude Differences, Flight 8

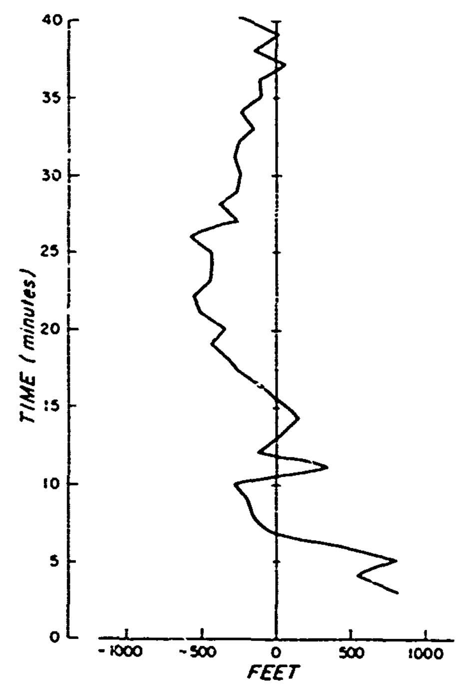


Figure 13. Altitude Differences, Flight 9

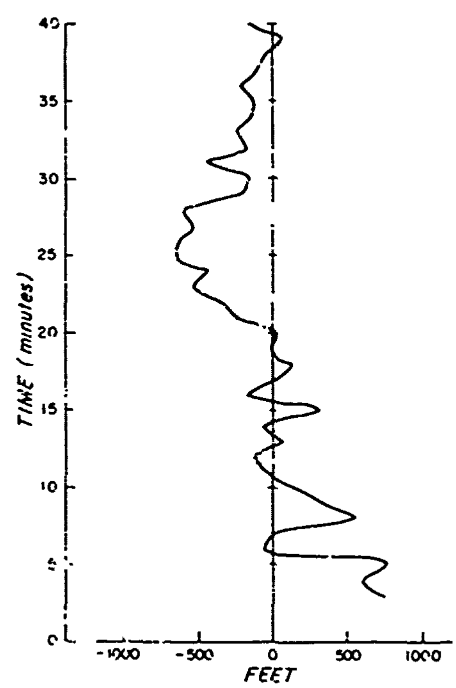


Figure 14. Altitude Differences, Flight 10

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